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Experimental Research of the Hot-Rolled Pipe Wall Sizing Process at the Reeling Mill of Pipe-Rolling Plant-140 in Conditions of Product Mix Extension

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Abstract. This experimental study was conducted on the equipment of pipe-rolling plant-140 with an automatic mill in order to give a qualitative and quantitative evaluation of the parameters which define the pipe wall sizing process in reeling mills. During investigation values of the power parameters of the process were recorded for different sizing routes. Conclusions about the special features of the wall sizing process and feasibility of extension of the reeling mill process capabilities were formulated.

The main areas of development of modern pipe rolling plants are increasing pipe accuracy, mastering pipe production of high-strength steel grades and extending the range of pipe diameters. In the process routes of hot-rolled pipe manufacture the pipe wall thickness accuracy is obtained through wall sizing at reeling machines by screw rolling. At present, there are no comprehensive procedures in place to describe this process.

The subject of this research was the main lines of the work stand of the reeling mill which is part of the process line of pipe-rolling plant-140 with an automatic mill [1]. Initially, this pipe-rolling plant was intended for manufacture of pipes up to 140 mm in diameter. Later on, due to mastering of the production process after many years of operation the range of pipe diameters was extended up to 159 mm, with a wall thickness from 5 to 14 mm, for pipes of carbon and low-alloyed steel grades. Currently, production capabilities for manufacture of pipes up to 178 mm in diameter are being developed at pipe-rolling plant-140 without significant modification of the existing equipment. As a result, the equipment failure rate has increased dramatically due to the increased process loads. Such failures lead to long shutdowns of the entire pipe-rolling plant-140, which, for sure, impairs its technical and economic performance. To solve the task of ensuring stable manufacture of high-quality products at pipe-rolling plant-140 is possible only through collection and analysis of the fullest information on parameters characterizing operation of the electric drive, on mechanical transmissions and power parameters of the pipe-rolling process. This can be done only as part of a comprehensive experimental research.

Reeling mills of pipe-rolling plants with an automatic mill perform a process operation of sizing the wall of rough pipes rolled at the automatic mill. This process is carried out through screw rolling in rolls turned at a plug angle and feed angle relative to the pipe axis. During this process, a pipe workpiece is expanding in diameter on a tapered mandrel with a cylindrical belt and is being sized at the same time in radial clearances formed by the positional relationship between the rolls and the mandrel. After the reeling mill the pipe is transferred to the sizing mill to have its final diameter formed.

The reeling mill of pipe-rolling plant-140 is a non-reversing screw rolling mill with individual drives for each of its three rolls (Figure 1).



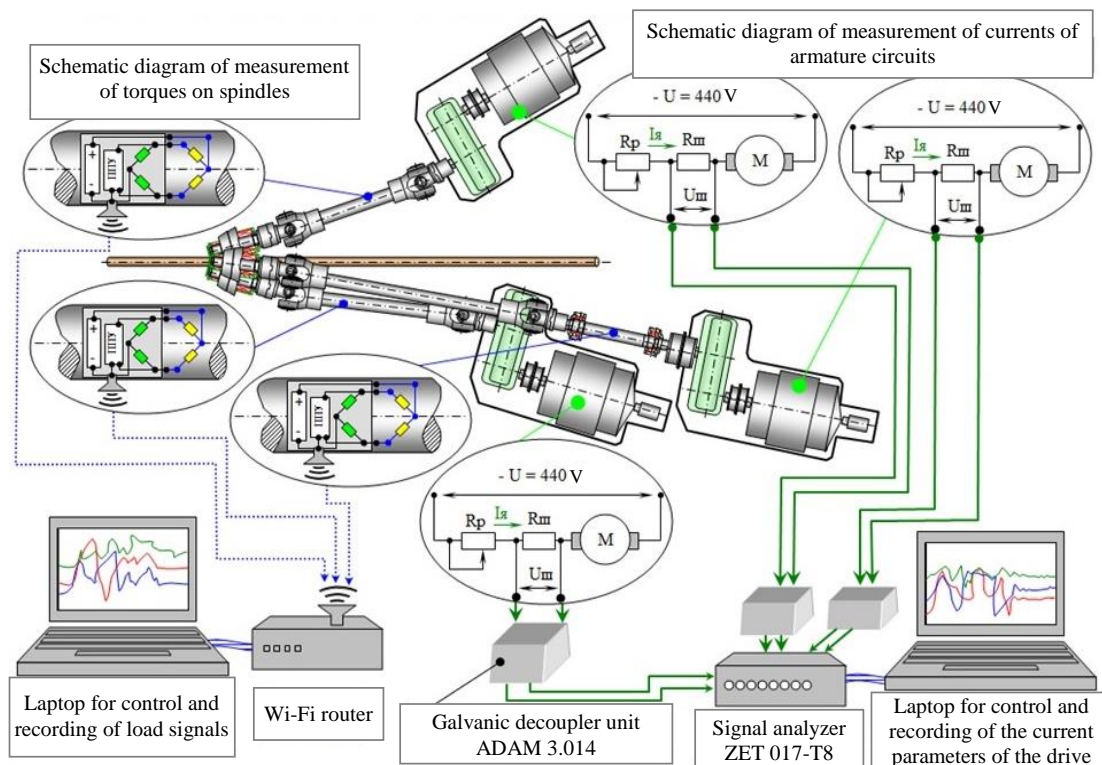


Figure 1. Drive design and schematic diagram of measurement and recording of load parameters in the drivelines of the work rolls of pipe-rolling plant-140 reeling mill during rolling.

Each of the rolls' drivelines includes a work roll assembly, universal spindles on rolling bearings, one-stage parallel-shaft reduction gear TsO-600, motor gear coupling M3-9, separately excited main drive motor P 143-4K with nominal power of 250 kW at nominal rotary speed of 500 rpm and constant voltage of 440 V. Drivelines of the bottom left and right rolls in the rolling direction are similar and differ only in the length of spindles and swivel twist angles. The driveline of the top roll includes additionally an intermediate shaft and connection gear coupling MZ-11. In line with the technical specification, the following nominal and maximum permissible load parameters for the reeling mill drive units are set:

- Nominal current/ cutoff current for the electric motor rotor – 612/1500 A,
- Nominal torque of the motor – 4.77 kN·m,
- Maximum torque transmitted by coupling MZ-9 – 29.4 kN·m,
- Maximum short-time/long-time torque transmitted by one spindle – 58.9/39.2 kN·m,
- Maximum short-time/long-time torque on the output shaft of the reduction gear – 31.4/16.7 kN·m,
- Maximum torque transmitted by coupling MZ-11 – 69.7 kN·m.

To identify the most loaded drive units of the reeling mill rolls, loading of each component was determined in reference to the threshold values when nominal torque of each of the main drives of the mill is applied. The value of the nominal torque equals 4.77 kN·m. The results of this analysis with regard to the reduction ratio are given below:

- Motor coupling MZ-9 – 16.2 %,
- Output shaft of the reduction gear by short-term load – 56.5 %,
- Output shaft of the reduction gear by long-term load – 76%,
- Toothed coupling MZ-11 of the line's intermediate spindle's drive – 28%,
- Spindles by long-time torque – 45.2 %,
- Spindles by short-time torque – 30.1 %.

As it follows from the data given, the maximum load falls on the main electric drives.

The schematic diagram of measurement and recording of the load parameters in the drivelines of the reeling mill work rolls during rolling is given in Figure 1. Two methods of measurements were used simultaneously for recording of parameters:

- monitoring system for electric drives' current parameters,
- monitoring system with the use of torques – wireless data transfer system.

The system of measurement and recording of the current parameters of electric drives is built on the basis of 8-channel signal-analyzer ZET 017-T8, which operates in the mode of a multichannel oscillograph in combination with a laptop with input signal sampling frequency from 0.1 Hz to 100 kHz and an analog-to-digital converter with resolution by digital signal of 2^{16} (16-bit signal). All measured parameters are converted into digital form with the use of the analog-to-digital converter and amplifiers integrated in the analyzer, recorded by the computer and simultaneously visualized on the monitor screen.

The currents of the armature circuits of the electric drives of the reeling mill work rolls were recorded from armature shunts (75mV/1500A) of the armature windings of each of the electric drives. Signals were connected to signal analyzer ZET 017-T8 through galvanic decoupler unit ADAM 3.014, which ensured protection of the measuring circuit. To evaluate dynamics of the current loads of the electric drives of the drivelines of the reeling mill work rolls, the sampling rate for the recorded signal was 0.02-0.04 s, which corresponds to the frequency of 25-50 Hz.

The original system for measurement and recording of load parameters, which was developed in Ural Federal University, is a wireless data transfer system. The equipment set includes a transmitter-receiver with an independent power supply unit, a router and a laptop. The system is able to operate both with analog and digital physical measuring transducers. A PLC is used to collect data, which are subsequently transferred via Wi-Fi to the laptop, where the obtained data are recorded, visualized and analyzed.

Torques transmitted by spindles of the rolls' drive were measured by electrotensometry [2]. Sockets of resistance strain gauges (half-bridge circuit) of 2 gauges FK-20-100 and transmitter-receivers were installed on the smooth part of the spindles and intermediate shaft to record torques. Strain-gage sockets were powered from independent power supply units – accumulators – which were installed in the transmitter-receivers. Output signals from strain-gage sockets were sent to the PLCs of the transmitter-receivers, digitized and transmitted through a Wi-Fi network to the router and further to the laptop. To evaluate dynamics of the processes running in the drivelines of the sizing mill work stands, the sampling rate for the main power parameters was equal to 0.016 s (62.5 Hz).

In addition, for each batch or lot of pipe workpieces the following data were recorded in a table format: steel grade, rough pipe dimensions after the automatic mill, gauge size, pipe diameter and wall thickness after the reeling mill, mandrel diameter and setting, roll feed angle, rolling speed, special rolling conditions.

No special methods for planning of the experiment were used during inspection of pipe-rolling plant-140 reeling mill due to the intensive production. Instead, series of measurements were taken during regular production processes for different pipe sizes and steel grades. The following pipe sizing processes were recorded during the research:

- finished pipe diameters – 108, 140, 146, 159, 168, 178 mm,
- finished pipe wall thickness– 5.0 ... 14.0 mm,
- pipe steel grades – 10, 20, 45, 09Г2С, 13KhFA, 30G2, 37G2F.

To decipher the obtained results, a software package which allows representing oscillograms in an easy-to-read format was developed. Analysis of the findings of the investigation included a qualitative analysis to identify the key features of pipe processing at the reeling mill, and a quantitative analysis to obtain the main relations between actual power parameters of the process and maximum permissible loads on the mechanical and electrical equipment.

Considering different steel grades, a wide range of diameters and different speed modes of electrical motors at the reeling mill, two most representative routes allowing evaluation of the influence of the mentioned factors were selected:

- pipe Ø 178 x 9.2 mm of steel grade 37G2F – this route is one of the most loaded because it is used for rolling of pipes of the largest diameter with a wall reduction of 0.8 mm of steel grade with the highest strain resistance (141– 211 MPa), and rolling is performed at speed corresponding to the first zone of electric motor speed control – not exceeding the nominal speed,
- pipe Ø 146 x 7.0 mm of steel grade 30G2 – this route is the most common route, it is carried out at increased rolling speeds corresponding to the second zone of electric motor speed control, with the strain resistance of steel within 128-185 MPa.

The strain resistance of steel was taken at the values of thermomechanical parameters [3] corresponding to the deformation conditions at the reeling mill: deformation degree of 10%, deformation rate of 10 s^{-1} , deformation temperature within the range $1000\text{--}900^\circ\text{C}$.

The qualitative analysis of the oscillograms for the batch of rolled pipes showed that there is a clear recurrence of the loading conditions between individual pipe workpieces, and that the torque values recorded with the use of the strain measurement method are consistent with the data obtained by recalculation through the currents of the electric motors' armature circuits.

The oscillograms of the electric motors' current loads, torques on the spindles in combination with the above mentioned limitations for different components of the reeling mill drive for the two most representative rolling routes are given in Figures 2 and 3.

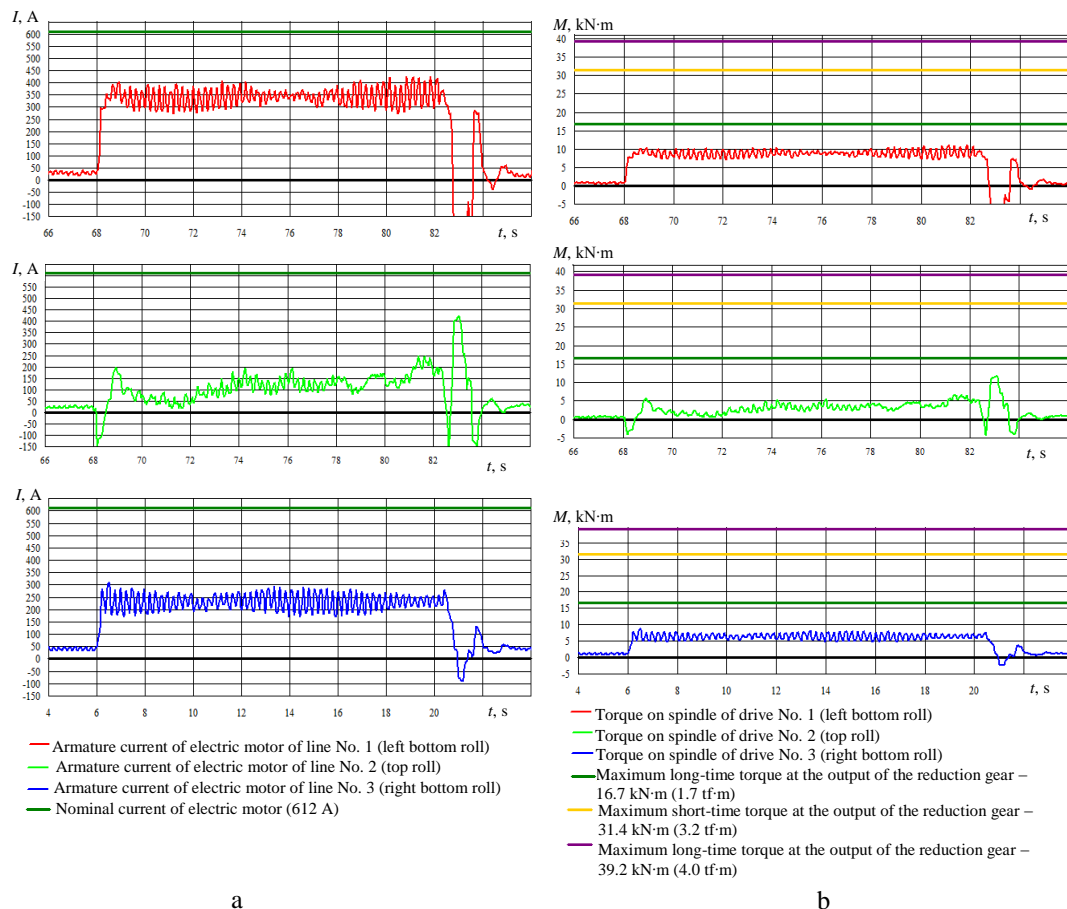


Figure 2. Oscillograms of the electric motors' currents I and torques on the reeling mill spindles M during sizing of pipe workpieces in the process of production of 178 mm diameter pipes with a wall thickness of 9.2 mm of steel grade 37G2F: (a) – oscillograms of the electric motors' drives; (b) – oscillograms of the torques on the spindles.

Analysis of the results of the investigation made it possible to come to the following conditions:

1. The pipe wall sizing process by the method of reeling on a retained mandrel in screw-rolling mills is a steady process and is characterized by significant oscillations of the torque and current values relative to the mean value. Oscillation amplitude amounts to 10 – 30 % of the mean load value, and oscillation frequency is double the rotation speed of a pipe workpiece – 4.0 ... 6.0 Hz.

The cause of this oscillating process is deformation of the side angles of rough pipes rolled at the automatic mill. As a matter of fact, that is the main technological function of the reeling mill under investigation, and such loading conditions are standard for this mill.

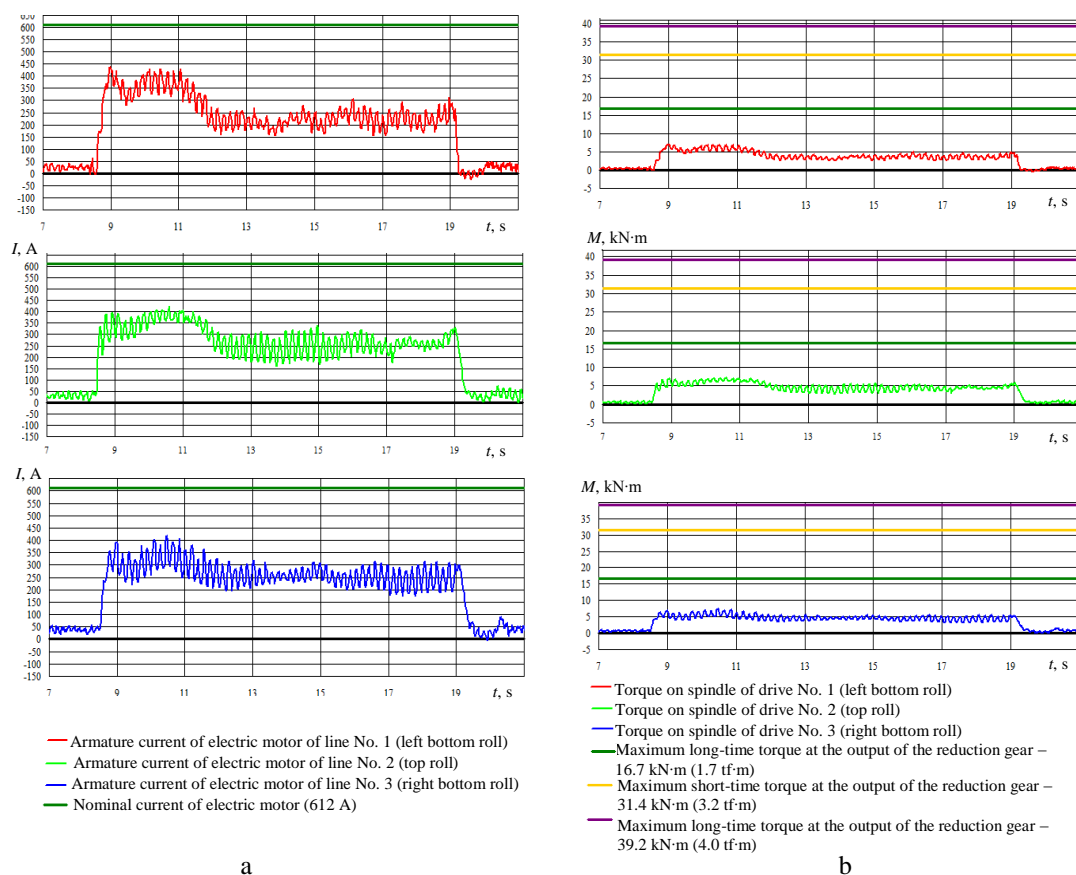


Figure 3. Oscillograms of the electric motors' currents I and torques on the reeling mill spindles M during sizing of pipe workpieces in the process of production of 146 mm diameter pipes with a wall thickness of 7.0 mm of steel grade 30G2: (a) – oscillograms of the electric motors' drives; (b) – oscillograms of the torques on the spindles.

2. For the two rolling routes under investigation the highest torques were recorded during production of 178 diameter pipes with a wall thickness of 9.2 mm of steel grade 37G2F. The maximum recorded level of torques 12 kN·m, which leads to loading of the reduction gear by long-time and short-time torque at 71.9% and 38.2%, and to loading of the spindles at 30.6 %. The total average torque on the spindles amounts to 15.5 kN·m. This leads to loading of the reduction gear by long-time and short-time torque at 73.9% and 28.7% respectively, and of the spindles – at 23.0%. The motor couplings transmit torques not exceeding 50% of the maximum permissible level. The load by torques is even less for the rolling route for manufacture of 146 diameter pipes with a wall thickness of 7.7 mm of steel grade 30G2. The maximum torque recorded during the investigation for this rolling route was 7.0 kN·m, with the total average value of 10.3 kN·m.

3. There have been little to no changes in the current loads of the electric motors when switching to manufacture of larger diameter pipes – the current loads have amounted to up to 75% of the nominal current. This is explained by the fact that the less intensive process of rolling 146 diameter pipes with a wall thickness of 7.7 mm of steel grade 30G2 is performed in the second zone of the electric motor speed control, which is characterized by power levelling and current increase with increase in speed.

4. The increase in the torques in the rolls' drivelines when switching to rolling 178 mm diameter pipes with a wall thickness of 9.2 mm of steel grade 37G2F versus process loads during rolling of pipes of conventional product range ($\varnothing 146 \times 7.7$ mm of steel grade 30G2) is equal to 53%, with only 10% due to the increased strain resistance of steel, the remaining portion being due to the increase in diameter.

Conclusions

The general conclusion is that switching to rolling of extended product mix at pipe-rolling plant-140 is feasible, since despite the growth of the process loads, they do not exceed the threshold levels. Moreover, there is a margin of 20%.

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